METHOD OF DETECTING FLICKER, AND VIDEO CAMERA USING THE METHOD

Field of the Invention

The present invention relates to a method of detecting lighting induced flicker in a video signal, and to a video camera equipped for carrying out this method.

Background of the Invention

Artificial lighting derived from alternating current sources, particularly fluorescent lighting, contains a strong brightness modulation component, or flicker, at twice the frequency of the alternating current sources. This factor of 2 arises from the power relation between instantaneous voltage of the alternating current sources and instantaneous brightness, and from the trigonometric relation $cos^2 (x = 0.5(1+cos(2x))$. Commonly encountered flicker frequencies are 100 Hz in Europe and 120 Hz in the United States. Although invisible to the human eye, flicker may be highly visible to image sensors. The problem is most apparent at low exposure values. An imagine sensor samples this modulation waveform as reflected from objects in the scene and reproduces it perfectly.

Solid-state sensors fall into two broad categories according to exposure method. One category is full-field, where all pixel elements of the sensor are exposed simultaneously. A second category is rolling window, where all pixel elements in a sensor row are exposed simultaneously, but the onset of exposure is delayed from row to row. Lighting flicker induces a periodic variation in luminance, known as banding. Banding is apparent in the time domain, and in the case of rolling-window sensors banding is also apparent in the vertical spatial domain.

In the case of the rolling-window sensors, should the camera and the frequency of the alternating current source be in perfect synchronization, the modulation pattern will be temporally frozen, appearing as static luminance banding down the image. However, the problem is compounded if camera field rates and frequency of the alternating current source differs by some amount, causing the luminance modulation bands to roll up or down the image. The rate of roll depends mostly on whether the camera is operating home or away, i.e., nominal frame rate may be a close sub-multiple of the frequency of the alternating current source. For example, a 50 Hz camera operating in the United States is operating away. Roll associated with a camera operating at home is extremely slow, while roll associated with a camera operating away is much faster.

As well as being visibly distracting to the viewer, luminance modulation generates considerable frame-to-frame differences in image streams which could, for example, make the difference between a software video CODEC performing acceptably. Thus, it

is important that a camera system be capable of detecting and cancelling artificial lighting flicker.

Detection of lighting flicker in the spatial domain is difficult in the case of rolling-window exposure sensors, and is much more difficult in the case of full-field exposure sensors. In the former case the difficulty is due to potential strong correlations between expected banding patterns caused by lighting flicker and variations in actual scene luminance.

U.S. Patent 5,053,871 discloses a still video camera which uses a previewing technique to provide automatic exposure control and flicker detection. However, there is a need to provide flicker detection in motion video cameras. U.S. Patent 5,272,539 discloses a video camera with flicker detection, but in this prior arrangement the detector frame rate is coupled with the video frame rate, which limits its usefulness.

Summary of the Invention

An object of the present invention is to provide a time-domain technique for detecting and reducing the frequency of flicker for motion video cameras, and which is also capable of being applied to both full-field exposure sensors and rolling-window exposure sensors.

Brief Description of the Drawings

An embodiment of the invention will now be described, by way of example only, with reference to the drawings, in which:

FIG. 1 is a schematic representation of a photosensitive array according to one embodiment of the present invention;

FIG. 2 illustrates a sampling method according to the present invention;

FIG. 3 is a block diagram of the flicker detection method according to the present invention; and

FIG. 4 is a block diagram showing use of the method according to the present invention in a video camera.

Detailed Description of the Preferred Embodiments

Referring to FIG. 1, a photosensitive array comprises a main array of pixels 10. It will be appreciated that FIG. 1 is highly schematic, with only a small number of pixels 10 being shown. Additionally, the photosensitive array comprises one or more (in this embodiment, two) super-pixels 12 and 14. Each of the super-pixels 12, 14 differ from the pixels 10 of the main array in two principal ways

The super-pixels 12, 14 are physically large in comparison to the pixels 10 of the main array so that they may stand a better chance of imaging some part of the scene which contains a flickering light source or reflects such a flickering source. In this example, each super-pixel is one entire column of photosensitive pixel elements 10 which have been electrically connected in common.

The super-pixels 12, 14 are exposed and sensed in a manner independent from the pixels 10 of the main array. While each line of the main array is sensed at the frame rate dictated by each application,

each super-pixel 12, 14 is sensed independently, usually at a rate much higher than the sensor frame rate to produce a suitable sequence of readings in each period of the lighting flicker. A convenient rate at which to sense each super-pixel 12, 14 is the line-rate of the application, which is usually some hundreds of times faster than the frame-rate.

Separate means must be provided to control the gain of each super-pixel 12, 14 to ensure its output sample falls within its linear operating range while maximizing dynamic range. As stated above, each super-pixel 12, 14 may be provided by connecting in common a column of standard size pixels, as indicated by interconnection line 20 in FIG. 1.

The output of each super-pixel 12, 14 is then operated on by a detection mechanism which will now be described with reference to FIGS. 2 and 3. The following description refers to the use of a single super-pixel. The detection mechanism operates ad infinitum on successive length-N sequences f(n) of compound samples. Each compound sample comprises one or more accumulated individual samples s(a) of the super-pixel. Each compound sample is spaced apart by an appropriate interval I, with the interval I being referred to as the compound sampling interval.

The individual super-pixel samples s(a) are accumulated over a fixed number of lines A, less than or equal to the interval I, and is referred to as the compound sampling aperture. Such accumulation allows an ensemble reduction of random components contained in each super-pixel reading s(a) at the expense of amplitude reduction of the super-pixel signal at the

frequencies of interest. This is attributable to the roll-off effect of a sampling aperture:

$$f(n) = \frac{1}{A}\sum_{a=1}^{A} s(a)$$

Note that in the cases where the desired compound sampling interval I cannot be expressed as an integer multiple of the sensor line interval, the compound sampling interval can be adjusted on an instantaneous basis to average out to the desired interval over time. The resultant phase jitter is tolerable as long as the compound sampling aperture remains constant. FIG. 2 illustrates the composition of the sequence f(n) for N=3.

One example of a detection mechanism takes the form of a bandpass filter tuned to the nominal frequency of the flicker. If the compound sample rate of the super-pixel is chosen as a multiple of the nominal flicker frequency, a straightforward detector might use the fundamental output component F(1) of a radix-N butterfly, or N-rotor. This circuit performs complex correlations with the fundamental Nth-root of unity to produce the instantaneous measure of complex flicker energy E:

$$E = F(1) = \sum_{n=0}^{N-1} f(n)\, e^{-2\pi \frac{n}{N}}$$

While radix-2 is the simplest butterfly, its response is phase-dependent and therefore unreliable.

As N increases, so does hardware complexity, and the smaller the compound sampling interval and potential aperture. We have found that N = 3 or 4 yields the most efficient and effective results.

These instantaneous complex flicker energy readings E must be averaged over time in some manner to produce a longer term estimate E′ of flicker energy. One example of an averaging mechanism is the first-order autoregressive filter, or leaky integrator, whose ability to track phase drift may be traded against noise immunity by its system time constant μ, and updating long term average E′ with an instantaneous measure E:

$$E' = E\mu + E' \ (1 - \mu)$$

The process of magnitude extraction affords some protection against phase drift, an inevitable consequence of short term or long term differences between actual and nominal flicker frequencies. The final flicker detection decision should be based on the magnitude or modulus of long term average E′. For example, if T is some programmable or predefined threshold, then the Boolean decision variable d can be defined as follows:

$$d = |E'| > T$$

Note that the compound sampling interval may be chosen to undersample the flicker signal, relying on the folding or aliasing effect to detect harmonics of a notional sub-harmonic of flicker. While this method allows longer exposure times or compound sampling

apertures, it is less able to track flicker frequencies differing from the nominal. This is so since the error in an instantaneous angular frequency is greater than that of the fundamental case for a given difference between actual and nominal flicker frequencies.

FIG. 4 shows the foregoing method used in a flicker detecting video camera. The main sensor array 10′ has its exposure setting controlled by either the output of an automatic exposure control circuit 18 of a known type, or by a flicker free exposure setting. The choice between these two is controlled by the Boolean operator and as derived above.

The actual correction of lighting flicker, once detected and identified in frequency, is relatively straightforward. To expand on the sampling analogy, it is well known that increasing a sampling aperture away from the therotical perfect sampling (i.e., convolution with a dirac-delta pulse train) causes a roll-off of the frequency response which obeys the equally well known sin(x)/x or sinc function. If the exposure window is considered as a sampling aperture, then those temporal frequencies present in the scene whose period coincides with the temporal duration of the exposure window, or harmonics of such frequencies, will be rendered invisible, as they coincide with nulls in the sinc function. Setting the exposure period to the inverse of a suspected flicker frequency or one of its harmonics will then provide effective banding removal.

A weakness of this scheme can arise under bright lighting conditions. Here the sinc function approaches the origin and no sinc function null can be found which corresponds to a desirable exposure

setting. Without recourse to additional exposure control mechanisms such as LCD shutter or mechanical iris, a compromise must be sought between acceptable banding and acceptable exposure setting. The invention thus provides a technique for detection and frequency identification of flicker which operates in the time domain, and which is applicable to both full-field exposure sensors and to rolling-window exposure sensors.

Modifications and improvements may be made to the foregoing embodiment within the scope of the invention.